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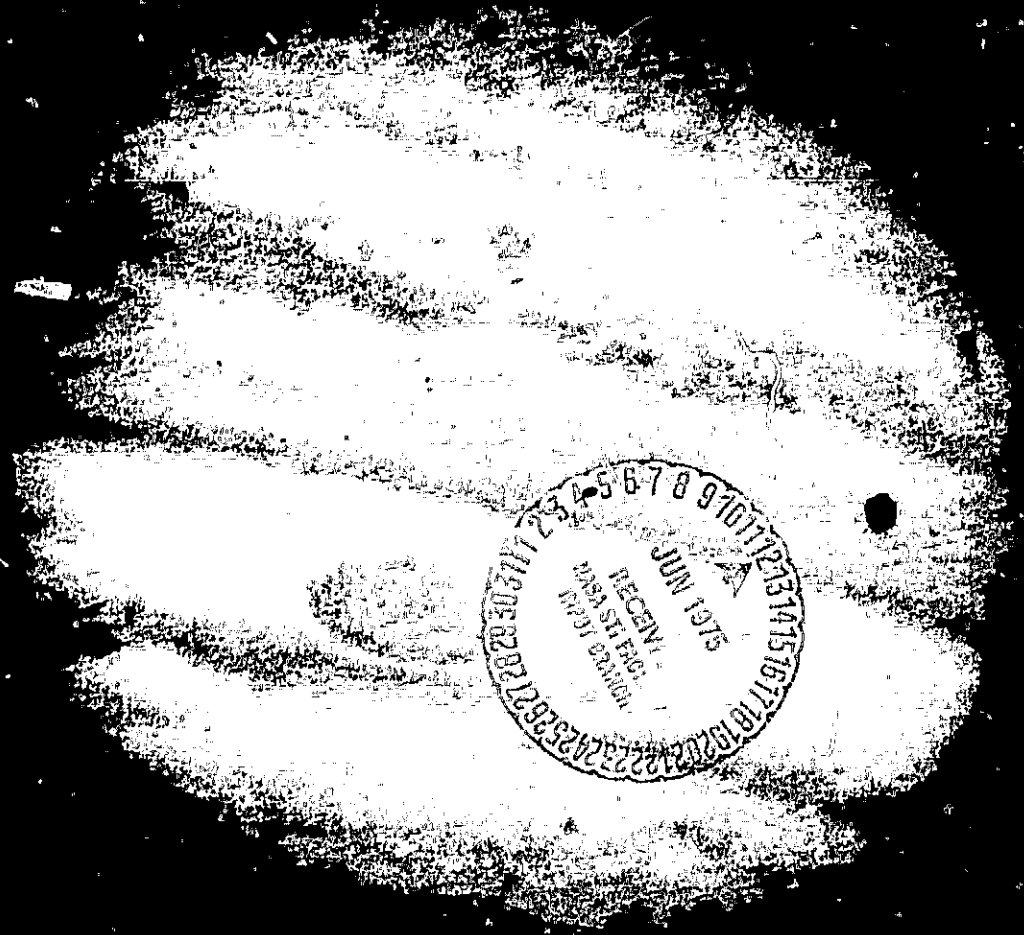
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# THE NOW FRONTIER

MAN LINKS EARTH AND PLANETS

# PIONEER TO JUPITER



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A NEW LOOK AT JUPITER: RESULTS AT THE NOW FRONTIER

# A NEW LOOK AT JUPITER: RESULTS AT THE NOW FRONTIER

## ENCOUNTER

Pioneer 10 hurtled 81,000 miles above the cloud tops of Jupiter, giant of the Solar System, at 6:26 p.m. PDT on December 3, 1973. But the total period of encounter with the largest planet and its miniature solar system of 12 large and small satellites lasted for several months. Inbound, Pioneer 10 crossed the orbit of the outermost satellite, Hades, on November 8. Outbound, the spacecraft obtained its final image of Jupiter on New Year's Eve 1973 as Pioneer 10 headed to the outer Solar System and onward into interstellar space, man's first emissary to the stars.

Scientists have analyzed some of the vast quantity of new information radioed to Earth by Pioneer 10. This sixth in a series of leaflets on the Pioneer mission summarizes results of the science experiments. But Pioneer 10 will continue to gather information about the outer Solar System until it passes the orbit of Uranus where its radio signals will become too faint to be received by the big antennas of the Deep Space Net: the time, 1980; the distance from Earth, almost 2 billion miles.

Pioneer results have contributed to a new understanding of the Solar System beyond Mars, of interplanetary space and the asteroid belt, and of the environment of the Jovian system. Pioneer 10 also provided new information about Jupiter and its big satellites.

## INTERPLANETARY SPACE BEYOND THE ORBIT OF MARS

### COSMIC RAYS

Cosmic rays are actually particles, the charged nuclei of atoms, moving at very high velocities and therefore possessing large kinetic energy. Low energy cosmic rays seem to be prevented from entering the inner Solar System, possibly by scattering regions of the solar wind. This wind consists of streams of electrons and protons and other ionized atoms emitted by the Sun. Fast and slow streams interact to produce magnetic scattering regions in interplanetary space which would scatter low energy cosmic rays. Pioneer 10 shows that to a distance of at least five times that of Earth from the Sun (5 astronomical units) scattering regions are being generated and no significant number of low energy cosmic rays enter from the Galaxy. Scientists do not expect

that Pioneer 10 will be able to detect such cosmic rays, should they exist in interstellar space, until the spacecraft has reached 20 to 30 astronomical units, where the solar wind scattering regions most likely subside.

If low energy cosmic rays are detected by Pioneer, they will help to throw light on the puzzle of why the flow of cosmic rays into the Solar System is about equal in energy to the incoming light from all the stars, whereas the output of cosmic rays from our Sun is only small compared with its output of light energy. Scientists have speculated that the impinging cosmic rays from the Galaxy might be purely a local effect from the violent explosion of an abnormal star or group of stars in our part of the Galaxy. Alternatively the intense cosmic ray flux may be the residue of charged particles from the explosive death of stars formed billions of years before the Sun and now extinguished, particles that became trapped in the magnetic fields of the Galaxy.

Scientists found, too, that the solar wind streams change as they move out from the Sun. At the distance of Jupiter the high speed gusts level out and the solar wind becomes less variable than at Earth's orbit. Stream energy is converted to heat energy with the result that the solar wind does not cool down as rapidly as might be expected.

Additionally, the science experiments of Pioneer 10 recorded an interstellar wind flowing into the Solar System along the plane of the Earth's orbit. This interstellar wind, consisting of uncharged hydrogen atoms together with a smaller quantity of helium atoms, originates from the gas between the stars.

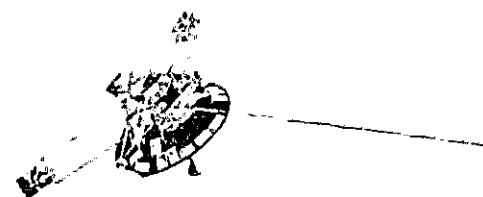
### DEBRIS IN SPACE

Sunlight reflected from and scattered by dust particles in space produces faint glows in the dark sky known as the Zodiacal Light and the Gegenschein, or counter glow. An astronomical theory that the Gegenschein, which is opposite to the Sun in the sky, might consist of sunlight reflected from small particles in space beyond Earth's orbit, was confirmed. Its faint glow extends even beyond the orbit of Mars and into the asteroid belt, but not beyond. Scientists also found that the Zodiacal Light decreases, as does the Gegenschein, with increasing distance from the Sun, except for some brightening within the inner zones of the asteroid belt. Thus the

Zodiacal Light is concentrated in the inner Solar System, and it fades almost completely at just over 3 astronomical units from the Sun.

The 175 million mile wide asteroid belt did not prove to be as hazardous to spacecraft as some speculations had suggested prior to Pioneer 10's epic voyage. Some astronomers had theorized that collisions of asteroids over billions of years might have produced a zone of destructive dust particles. Pioneer 10 penetrated the asteroid belt safely and emerged undamaged. So did its sister spacecraft, Pioneer 11. The asteroid belt is not a serious hazard to spacecraft passing through it.

However, Pioneer 10 did find a concentration of dust particles around Jupiter which, although not a hazard to Pioneer-type flybys, might represent a danger to spacecraft in some orbits about Jupiter.



## THE JOVIAN SYSTEM

### SIZE OF JUPITER

Pioneer 10's path through the Jovian system, observed by tracking and analyzing changes to the spacecraft's radio signal, reveals that Jupiter, together with its satellites, is heavier than previously calculated by about twice the mass of Earth's Moon. Jupiter itself is 317.8 Earth masses—about one Moon mass heavier than previously thought. The Earth contains 81 Moon masses.

A new measurement of the diameter of Jupiter and of the planet's polar flattening gives the polar diameter as 82,967 miles and the equatorial diameter, 88,734 miles. Jupiter is ten times as flattened as is Earth, probably because it is nearly all liquid and is rotating very rapidly. An object on the topmost clouds of Jupiter at the equator travels at 22,000 miles per hour because of the planet's spin, compared with only 1,000 miles per hour for an object on Earth's equator. Centripetal forces oppose gravity and allow the equator to bulge.

## THE GALILEAN SATELLITES

Pioneer 10 provided new information about the large satellites of Jupiter, often referred to as the Galilean satellites. In terms of the mass of Earth's Moon, the big Jovian satellites are; Io, 1.22, Europa, 0.67, Ganymede, 2.02, and Callisto, 1.44 lunar masses. The new measurement of the mass of Io is 22 percent greater than before Pioneer 10.

The density of the big Jovian satellites decreases, like the planets, with increasing distance from the central body. Io's density is 3.5 times that of water; Europa's, 3.14; Ganymede's, 1.94; and Callisto's 1.62. The two inner satellites might accordingly be rocky bodies swept free of water ice by primordial heat of Jupiter soon after the big planet formed, while the outer satellites might contain a large proportion of water ice. All the satellites now have very cold surfaces; even on their sunlit hemispheres the temperature is only  $-245^{\circ}\text{F}$ .

Pioneer 10 obtained images of Ganymede (Figure 1) and of Europa. Ganymede has large flat circular plains, hundreds of miles across, somewhat similar to those of Mars, Mercury, and the Moon. There are also bright and dark areas on the satellite, and markings that might be impact craters. Europa was too far away from Pioneer to provide an image showing more than vague markings, like a view of Mercury as seen from Earth.

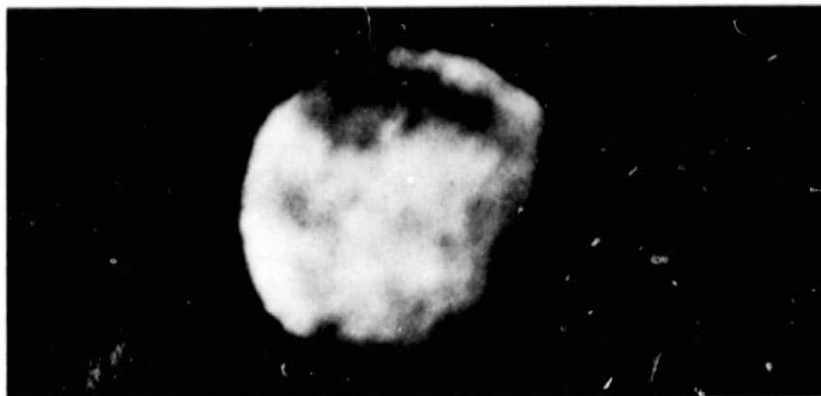


Figure 1. Ganymede, Jupiter's largest satellite.

As Pioneer 10 hurtled through the Jovian system it passed behind Io and was occulted. As the spacecraft's radio signals to Earth passed through the atmosphere of Io they were changed, and from the changes scientists are able to determine that Io's atmosphere is 20,000 times less dense than Earth's atmosphere, but reaches some 70 miles above the satellite's surface. Io's ionosphere was discovered to be 450 miles high above the dayside of the satellite, which makes Io a unique body in the Solar System because it possesses an ionosphere while immersed in the strong magnetic field of its mother planet. Scientists were surprised to discover that Io is also embedded in a vast cloud of hydrogen gas that extends a third of the way around the orbit of the satellite.

## THE MAGNETIC FIELD OF JUPITER

Like the Earth, Jupiter has a magnetic field. Pioneer 10's measurement shows that this field at Jupiter's cloud tops is probably ten times the strength of Earth's surface field. The Jovian magnetic field is tilted about 10 degrees to the axis of rotation of Jupiter (Figure 2), and the center of the field is offset from the center of the planet about 1,320 miles north and 4,850 miles out toward the equator. Because of the tilt, a passing spacecraft sees the field wobble up and down through an arc of 20 degrees once every 10-hour rotation of the planet.

A magnetosphere surrounds Jupiter, as one surrounds the Earth, and protects the planet from the solar wind. And like the Earth, Jupiter has a bow shock produced when the high speed solar wind, carrying its magnetic field, interacts with the strong magnetic field of Jupiter. The solar wind is abruptly slowed down, thereby increasing its temperature ten times.

Between the magnetosphere and the bow shock is a turbulent region called the magnetosheath in which the solar wind is deflected around the magnetosphere. All these phenomena are experienced on Jupiter on a scale vastly greater than around Earth. Pioneer's points of crossing Jupiter's bow shock showed it to be about 16 million miles wide along the trajectory. But the magnetosphere stretches three-dimensionally around Jupiter and if it could be seen from Earth as a visible object it would appear four times as big as the Sun or Moon appears in Earth's skies.

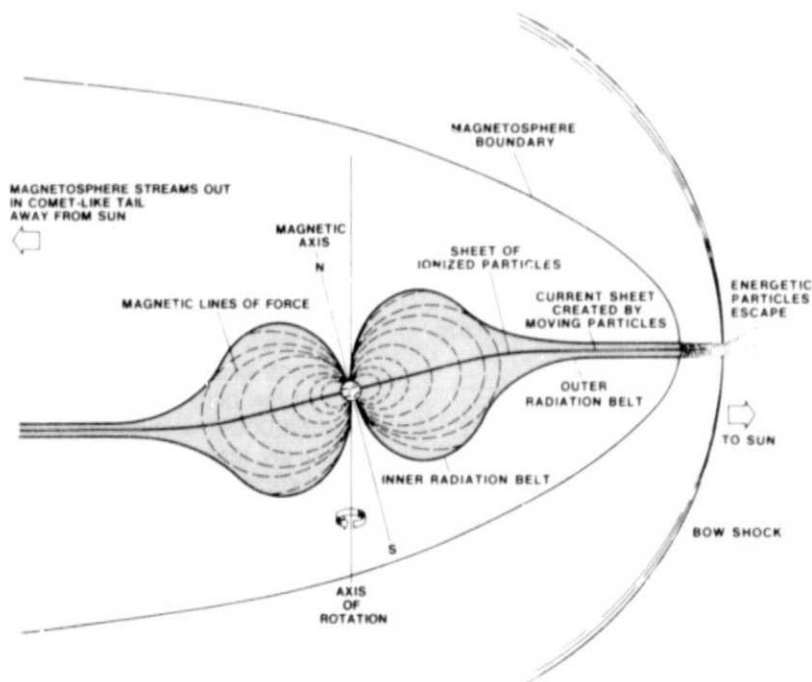


Figure 2. The magnetosphere of Jupiter.

The magnetosphere consists of an inner region shaped something like a doughnut, with Jupiter in the hole. Out-

side of the doughnut ring is an unusual outer region caused in part by ionized gas being thrown into space as a consequence of the magnetosphere's rapid rotation with the planet. Very different from Earth's magnetosphere, this outer region is flattened. Within it ionized particles form an electric current sheet around the planet, a sheet which flops around like the brim of a fedora hat as Jupiter rotates its tilted magnetic field.

At times the solar wind pushes strongly on the magnetosphere so that the outer magnetic field collapses and accelerates low energy particles to such high velocities that they are squirted in pulsar-like jets from Jupiter. A new discovery by Pioneer 10, these particle jets make Jupiter the second source in the Solar System—the Sun being the first—of high energy particle radiation. Scientists have now confirmed that these particles have been detected at Earth's orbit for several years, but before Pioneer's discovery, their origin was unknown.

Jupiter's inner magnetic field extends from the center of the planet to about 880,000 miles, while the outer field varies between 2 and 4 million miles or more. Because the poles of Jupiter's field are reversed compared with Earth's poles, a north-seeking magnetic compass would point south on Jupiter.

## RADIATION BELTS

Particles from the solar wind, trapped in the magnetosphere of Jupiter, produce radiation belts as they do in Earth's magnetosphere (Figure 3). An inner belt corresponds to the inner magnetosphere and traps electrons and protons of a wide range of energies. Intensities are some

10,000 times greater for electrons there than in Earth's belts. Protons are several thousand times as intense as in Earth's belts. Such high radiation intensities have previously been measured only after a nuclear explosion in Earth's upper atmosphere.

In the outer belt, corresponding to the brim of the fedora, a region of high energy electrons is surrounded by an extensive cloud of less energetic protons and electrons.

While Earth's Moon is far beyond Earth's radiation belts, the large Galilean satellites of Jupiter (I, II, III, and IV) are immersed in the Jovian belts and sweep up particles, thereby reducing the total radiation near Jupiter to many times less than what it would be without the presence of the satellites.

## JUPITER'S INTERIOR

Pioneer 10 has shown that Jupiter is a huge spinning ball of liquid hydrogen without any detectable solid surface. The planet may have a small rocky core, but this is still uncertain. Also, Jupiter was probably very much hotter when first formed. Billions of years ago its radiation was probably intense enough to sweep its inner satellites free of water ice, leaving them denser than the outer satellites.

Jupiter's gray-white zones are cloud ridges of rising atmosphere circling the planet. They project about 12 miles above the belts which are cloud troughs of descending atmosphere.

Jupiter is too hot to solidify. It is almost certainly nearly all liquid with its atmosphere being only about 1 percent of its

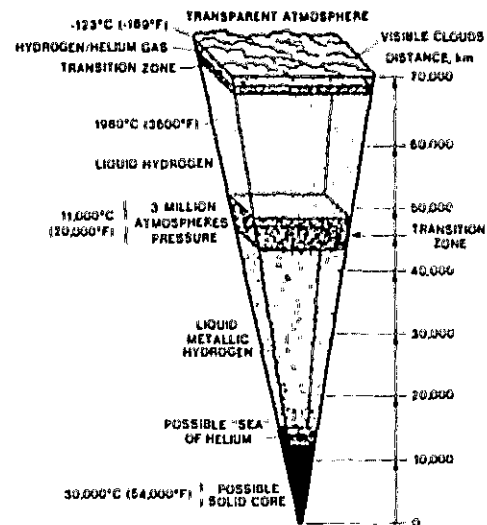


Figure 4. Pioneer 10 confirms models of Jupiter that suggest the planet is nearly all liquid with a very small core and a deep atmosphere.

total mass. The planet is about 82 to 87 percent hydrogen and 12 to 17 percent helium, with traces of other gases such as ammonia and methane. The atmosphere is probably not more than 600 miles deep. At its bottom there is not a liquid surface like Earth's ocean, but a gradual transition from gas to liquid at a temperature of about 3,600°F (Figure 4). At 1,800 miles depth, Jupiter is entirely liquid, while at 15,000 miles below the cloud tops the pressure from the weight of hydrogen above is so great that liquid hydrogen changes into a form which readily conducts heat and electricity and is called metallic hydrogen. But it is still a liquid because temperatures are too high—estimated at 20,000°F—for hydrogen to become a solid.

Radiating heat at 2.3 times what it receives from the Sun, Jupiter loses heat into space at an enormous rate. Temperature at the center of the planet must be about 54,000°F to maintain the heat flow. This is six times the temperature of the bright surface of the Sun (the photosphere). But at the cloud tops of Jupiter the temperature is only -184°F. Between these two extremes there must be vast regions of Jupiter where temperatures could be suitable for life, providing such life could live in a hydrogen rich atmosphere and resist rising and falling air currents carrying it to too hot or too cold levels of the atmosphere.

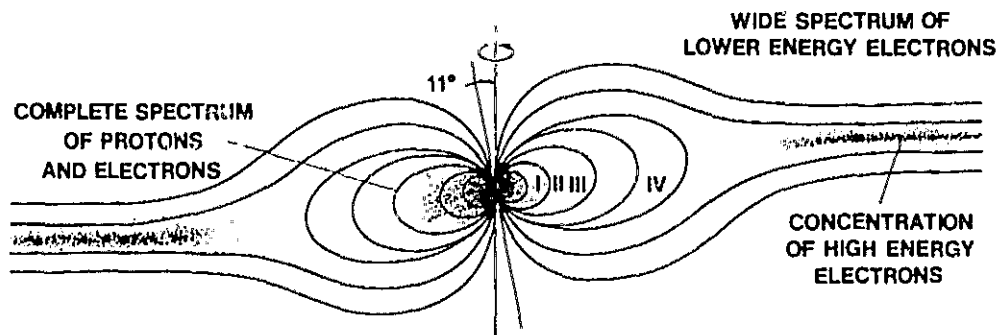


Figure 3. The radiation belts of Jupiter and its magnetic field with the position of the Galilean satellites (I, II, III and IV) relative to the belts.

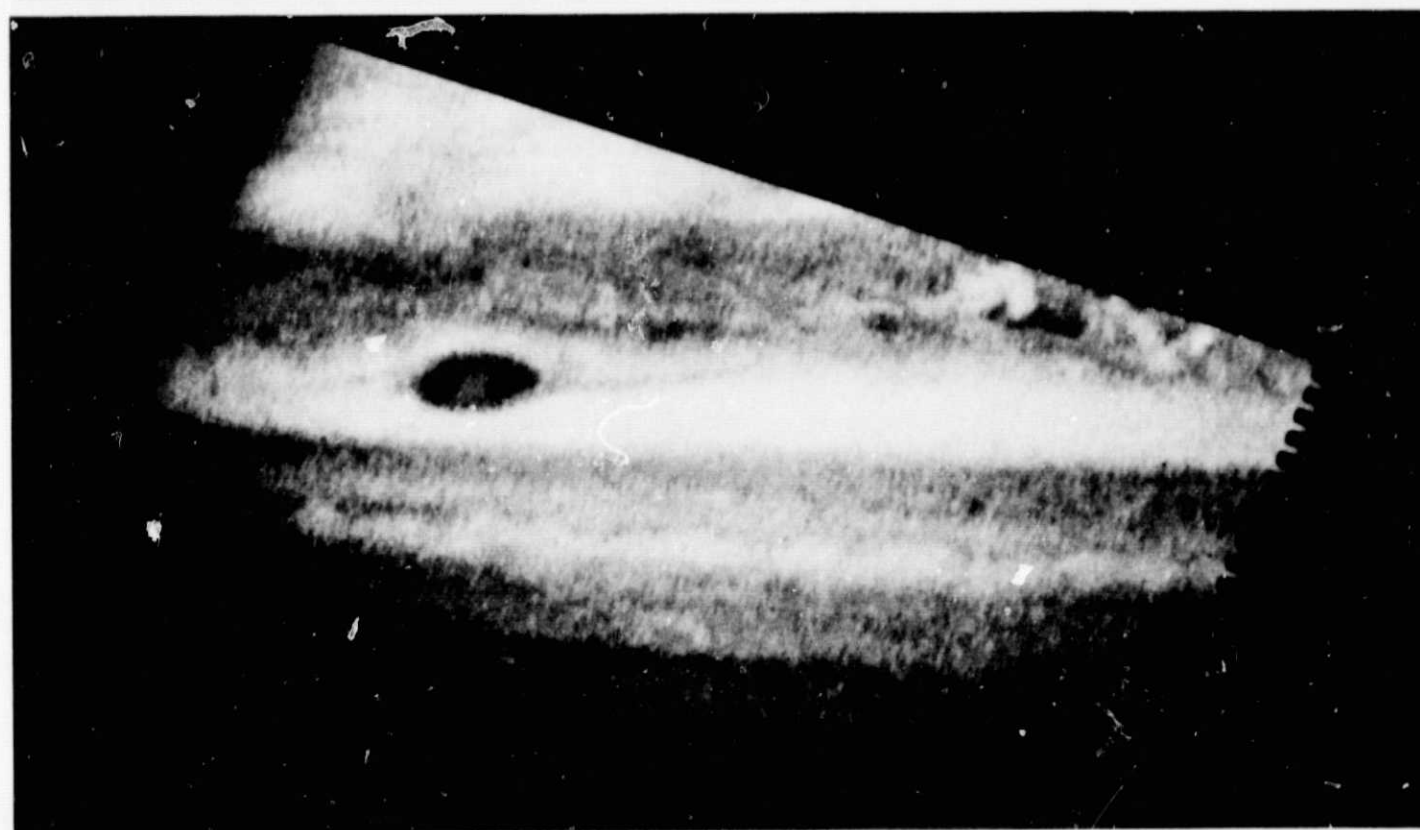
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**JUPITER'S WEATHER**

Spin-scan images of Jupiter provided close-ups not possible from Earth (Figure 5 and 6) and allowed scientists to understand the circulation patterns in the Jo-

vian atmosphere. Clouds form in Jupiter's atmosphere by condensation as they do on Earth. But Jupiter's clouds are probably of ammonia and ammonium

compounds as well as water. The top-most clouds are thought to be crystals of ammonia.



Figures 5 & 6. Close-up spin scan images of Jupiter showing details of the belts and the spots.

# JUPITER WEATHER

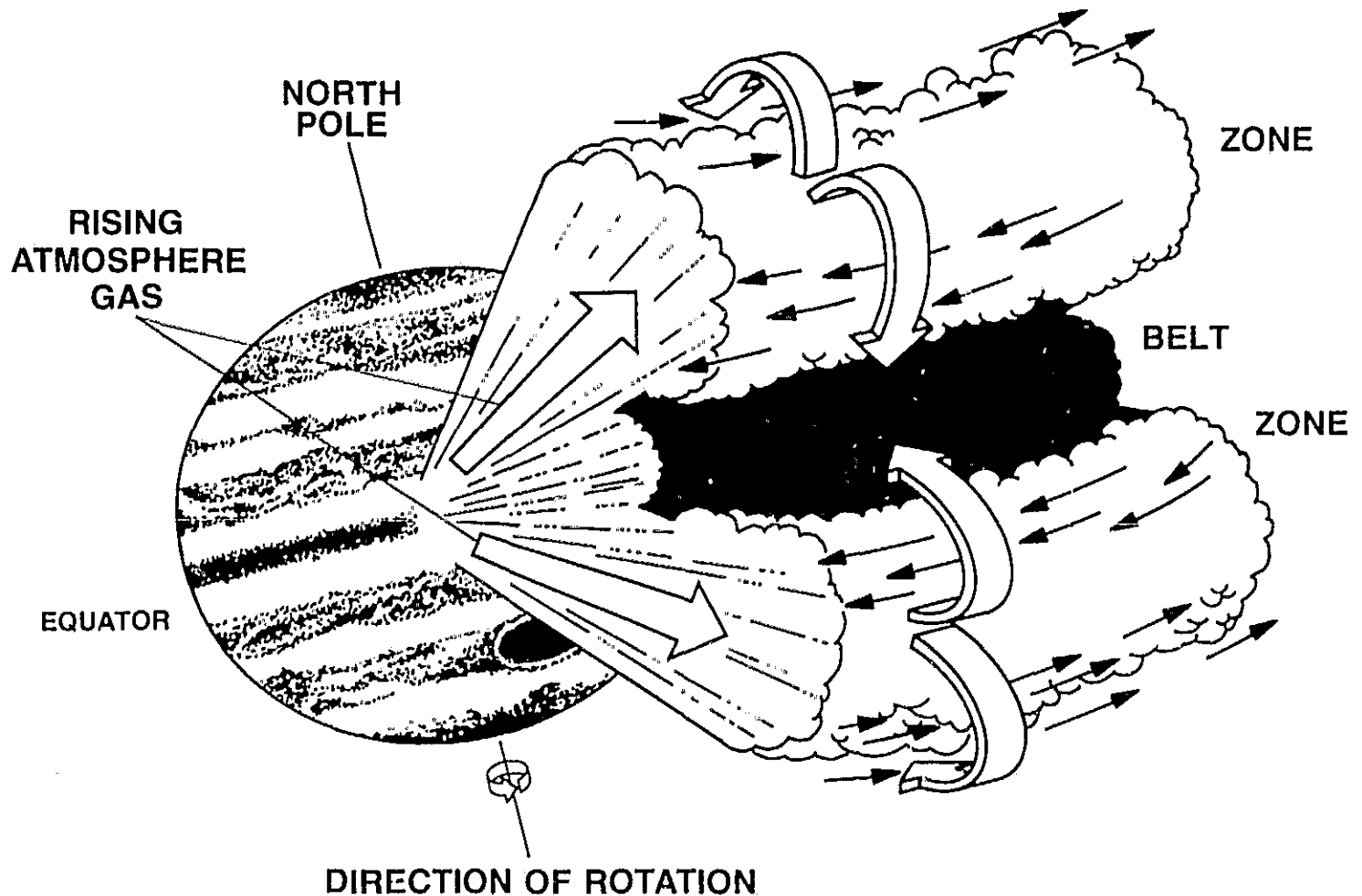


Figure 7. Atmosphere gas, which would move toward the equator by convection, instead, due to coriolis force, moves around the planet against the direction of rotation. Gas which would move toward the poles instead moves around Jupiter in the rotation direction.

The semi-permanent belts and zones of Jupiter (Figure 7) seem similar to Earth's cyclones and anticyclones—regions of rising and falling gas—distorted by forces produced by the rotation of the planet coupled with movements of the atmosphere up and down and northward and southward. On Earth these forces, known as coriolis forces, produce the circular wind patterns of cyclones and anticyclones and trade wind patterns. On Jupiter the forces are much greater and stretch the cyclones and anticyclones around the planet into the distinct belts and zones of Jupiter.

Spots on Jupiter, including the Great Red Spot, are now thought to be hurricane-type features consisting of groups of persistent thunderstorms. Pioneer 10 also confirmed that red spots which have been seen for some time in the northern hemisphere of Jupiter are small replicas of the Great Red Spot. They behave as ascending masses of gas flowing out from tops which poke several miles above surrounding clouds.

Jupiter differs from Earth in its cloud patterns because the energy driving them comes mainly from inside the planet and

is evenly distributed night and day around the planet. By contrast, Earth's weather patterns derive their energy from the Sun which is concentrated in the tropics on the daylight hemisphere of the planet. It is because of the internal energy source that prominent weather systems on Jupiter, such as the Great Red Spot, can last for many years.



## FUTURE POSSIBILITIES

As a result of information gained by Pioneer 10's encounter with Jupiter, space mission planners can now devise trajectories for spacecraft that take them quickly through the regions of intense radiation. They now know how to safeguard spacecraft that are to use the gravity slingshot of Jupiter to reach the outer planets of the Solar System. Pioneer 10 has thus opened a gateway to the outer planets.

Pioneer's confirmation that Jupiter has a warm extended atmosphere of hydrogen causes space experts to enthuse about opportunities for further exploration of the giant planet. Measurements of the environment of the Jovian system have shown that spacecraft can be placed into elliptical orbits around Jupiter and survive. And the hydrogen rich, hot atmosphere, makes it feasible to use probes dropped from such an orbiter to penetrate deep without burning up. Such probes stand a good chance of surviving entry into the atmosphere and making measurements within it.

They might even sample the Jovian atmosphere. Since some modern theories suggest that Jupiter may have formed before the Sun itself, Pioneer 10's exploration of Jupiter may have opened the way to sample material from the protosolar nebula.

## STUDENT INVOLVEMENT

1. *An Exercise in Encounter by Sensors:* For this classroom project the teacher should provide three pairs of objects such as; a) football and inflated rubber balloon, b) clear bottle containing vinegar and clear bottle containing cold coffee, and c) block of natural sponge and block of plastic foam rubber.

The objects are screened from the class in general and each student is allowed to inspect them individually and make notes of his observations by three senses; first sight, next touch, and third, smell. The student is asked to write down a description of the objects in terms of these three sensors and to describe how the objects in each pair differ.

The student is finally asked to write a short report explaining how this exercise is analogous to a spacecraft's instruments probing a distant planet to determine its physical characteristics and composition.

2. *Defining Environments:* Individual students are asked to compile a table showing the way in which the student would express the environment in terms of the five senses; sight, touch, taste, smell, and hearing, for the following:

- a) Surface of the Sun
- b) Land surface of the Earth
- c) Interplanetary space
- d) The asteroid belt
- e) Atmosphere of Jupiter
- f) Radiation belts of Jupiter
- g) Interstellar space.

The student is also asked to describe what important elements of the environment would be missed by observations with the five human senses in each of the above.

## FURTHER READING SUGGESTIONS

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